ASCC 3-D Laser Scanning Study

Part 2: Eight participants used scanners to determine F-numbers

by William Paul, James Klinger, and Bruce A. Suprenant

Joint ACI-ASCC Committee 117, Tolerances, is preparing a new document, “Guide to the Use of 3-D Laser Scanning for Concrete Tolerances.” In anticipation of that document, the American Society of Concrete Contractors (ASCC) organized a study to evaluate laser scanning for concrete quality assurance applications. The study was conducted on a construction site in Walnut Creek, CA, on October 6-7, 2018. Eight participants (each comprising one to three individuals) scanned portions of the project to compare against independently obtained reference data. The first part of this study, focusing on the accuracy of laser scanning target coordinates, was reported in *Concrete International* in January 2019.[1] Details on the concrete structure at the podium and ground levels used in this study are found in that article.

Study Objectives

The second part of the study focused on the use of laser scanning technology to evaluate floor flatness and levelness, and it consisted of three parts:

- Taking laser scanner measurements to determine F-numbers in accordance with ASTM E1155, “Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers”;
- Comparing F-numbers obtained by laser imaging devices to those obtained by a Type II device (Dipstick®); and
- Evaluating repeatability and reproducibility of F-numbers by laser scanning.

While ASTM E1155 states that a laser imaging device may be used to collect data for F-numbers, that standard’s precision and bias statement applies only for Type II devices. Thus, a major goal of the work was to provide data in support of development of a

Fig. 1: The yellow shaded area indicates the portion of the podium level slab where 12 sample measurements lines were marked for use in F-number analysis. The lines varied in length from 20 to 35 ft (6 to 11 m). Point coordinates of the start and end of each line were measured using a total station, and these coordinates were provided to each participant. Eight participants performed a laser scan on the lines on two separate days and provided composite F-numbers determined per ASTM E1155 in addition to information on each sample measurement line. For comparison, a Type II device (Dipstick®) was used to collect data twice on the same sample measurement lines

precision and bias statement for laser imaging devices used to evaluate floor flatness and levelness.

F-numbers on designated measurement lines

Twelve sample measurement lines were marked on the top surface of the podium slab (Fig. 1). In accordance with ASTM E1155, equal numbers of lines of equal aggregate length were provided both parallel to and perpendicular to the longest test section boundary, and the line lengths were sufficient to yield the minimum number of z_i readings for the test area. Point coordinates of the start and end of each line were measured by a total station and provided to each participant to use in locating the lines in their laser scans. The participants performed their laser scans twice, once on Saturday and again on Sunday, to obtain data for repeatability and reproducibility studies. On the same days, a Type II device (Dipstick) was used to collect data on the sample measurement lines.

Figure 1 illustrates the location of the sample measurement lines on the podium level used for the study. The lines ranged from 20 to 35 ft (6 to 11 m) in length. The total floor area under evaluation was about 6000 ft^2 (557 m^2), and the sample measurement lines included 222 z_i readings. A data form was provided so that each participant could enter their data for each sample measurement line.

Composite F-numbers with participant-selected measurement lines

Laser scanner operators selected their own sample measurement lines and collected data in accordance with ASTM E1155 on two separate days on the ground level slab (Fig. 2). Sample measurement lines selected on the second day were required to be at about 45 degrees relative to the lines selected for the first day. As with the podium level, the total area of the test slab was about 6000 ft^2. The day before the participants conducted their initial scan of the ground level slab, an operator with a Type II device also selected lines and collected data in accordance with ASTM E1155.

Participant instructions

Each participant was instructed to conduct their survey in accordance with ASTM E1155. They were asked to set up and perform their work independently, using what they considered to be best practices for the work. Data reporting forms were provided, and the participants were instructed not to share their forms.

Participant information

The participants consisted of personnel from four contractors, two consultancies, and representatives from two laser equipment manufacturers. While many of the participants were local to the San Francisco-Oakland Bay, CA area, there were also participants from Colorado, Texas, and Florida. All were volunteers, and they and their companies were not reimbursed for their time or travel expenses.

Each participant worked independently. Raw data were shared with the participants after all had completed measurements; however, participants are identified anonymously in the dataset. Information on each participant's laser type and stated experience level are shown in Table 1.

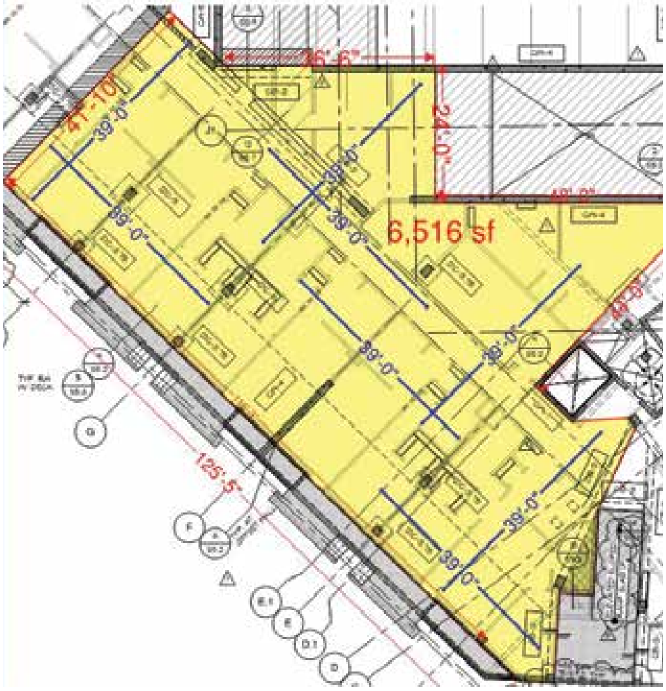

Fig. 2: The yellow shaded area represents the portion of the ground-level slab where each laser scanning participant team was directed to determine composite F-numbers. Each team independently selected sample measurement lines on the first day of the study. On the second day, the teams were required to select lines that were about 45 degrees relative to the first day's lines. An operator with a Type II device also selected lines and collected data in accordance with ASTM E1155

Basic Data for F-numbers

Type II device—Consolidated Engineering Laboratories (CEL) was contracted to use a Dipstick to measure 12 sample measurement lines on the podium slab. This test was done twice to determine repeatability (Table 2). ASTM E1155 states that "The repeatability standard deviation for both F_F and F_L is less than 0.25." The 95% repeatability limits are 2.8 times the repeatability standard deviation which is equal to 0.70. The composite F-number values are shown in Table 2. The difference in measured F_F and F_L values are both well within the 95% repeatability limit.

ASTM E1155 also states that "when operators and equipment models (of the same fundamental type of measurement apparatus) are varied, but the layout pattern is retained, the repeatability standard deviation goes up to about 0.3." Obviously, the laser scanner is not the same fundamental type of measurement apparatus and cannot be compared to the 0.3 repeatability standard deviation.

Table 1:
Laser scanner type, software used to calculate F-numbers, and experience level for participants

Participant	Laser type	F-number software	Experience level	
			Total scans	F-number scans
A	Faro S150	Rithm	10 to 100	0 to 5
B	Leica P40	Excel	100 to 250	
C	Leica RTC360	Rithm	More than 250	"Performed a number of scans and registrations that we knew would be used for F_F/F_L; however, our contractor clients would often have calculated, marked, and laid out the lines."
D	Faro S150			100 to 250
E	Faro X330			More than 250
F	Faro S350			100 to 250
G	Trimble TX8	Trimble		10 to 100
H	Leica P40	Excel		More than 250

Note: Faro, Leica, and Trimble indicate scanners marketed by Faro Technologies, Inc., Leica Geosystems AG, and Trimble, Inc., respectively. Rithm and Excel are software packages used to process the laser data into F-numbers

Table 2:
Composite F-numbers obtained using Type II device measurements

Podium	F_F	F_L	Ground	F_F	F_L
Run 1	24.73	23.34	Run 1	24.57	19.69
Run 2	24.75	23.20	Run 2	NA	NA
Difference	0.02	0.14	Difference	NA	NA

CEL used a Type II device to measure 10 sample measurement lines on the ground level slab. Because this was performed only once, no information on the repeatability or reproducibility was obtained. However, ASTM E1155 has a precision and bias statement that contains this information.

Laser—Table 3 provides the composite F-numbers for the podium level, where the participants used the same 12 sample measurement lines. The table also shows the difference between the composite F-numbers for the two measurements. Laser participant G used software that was unable to collect data for operator-designated lines and thus could not provide comparative data.

Table 4 provides the composite F-numbers for the ground level, where the participants selected their own sample measurement lines. Note that laser participants F and G selected the same lines on both days and thus failed to comply with the provided instructions.

F-number observations

Podium level—The immediate observation that can be made with Fig. 3 is that the repeatability of F-numbers with laser scanning is basically on par with using a Type II device. While repeatable, the laser imaging devices do not appear to provide the same values as the Type II device. According to ASTM E1155, if the laser imaging device and the Type II

Table 3:
Podium-level composite F-numbers obtained using laser measurements

Participant	Podium	F_F	F_L
A	Day 1	32.11	24.60
	Day 2	31.93	23.90
	Difference	0.18	0.70
B	Day 1	29.50	23.90
	Day 2	29.00	22.90
	Difference	0.50	1.00
C	Day 1	31.18	22.67
	Day 2	31.18	22.67
	Difference	0.00	0.00
D	Day 1	29.21	23.71
	Day 2	32.05	24.00
	Difference	0.84	0.29
E	Day 1	32.84	25.64
	Day 2	32.85	25.51
	Difference	0.01	0.13
F	Day 1	31.10	23.65
	Day 2	30.49	23.66
	Difference	0.61	0.01
G	Day 1	NA	NA
	Day 2	NA	NA
	Difference	NA	NA
H	Day 1	27.36	24.12
	Day 2	24.20	23.11
	Difference	3.16	1.01

device provided the same information, they should be within 0.84. If we round up the Type II device F-numbers to be F_F 25 and F_L 23, then we should expect that the laser imaging device would provide reasonable values if they are within ±1 of the Type II device values. This would be a range of F_F of 24 to 26 and F_L of 22 to 24 for the laser imaging device.

For the 14 F-numbers measured by a laser imaging device, 10 meet the criteria for F_L. However, only one measurement meets the criteria for F_F. In other words, floor levelness values obtained by laser imaging devices were reasonably close to the values measured by the Type II device, but the same cannot be said for floor flatness. The reported floor flatness values obtained using laser imaging devices ranged from 24.2 to 32.8. While one laser F_F measurement was within 1.04 of the composite F_F obtained by the Type II device, the other 13 laser F_F measurements were considerably higher. The differences between Dipstick and laser-measured flatness and levelness may be the result of relative instrument accuracy. The Dipstick manufacturer indicates that the instrument has an accuracy of 0.0125 mm (0.0005 in.) (refer to Reference 2); this is at least two orders of magnitude better than the accuracy of elevations found using laser scanners (refer to Reference 1).

Ground level—Unlike the podium-level measurements, where every participant measured the same 12 sample lines, measurement lines for the ground level were independently selected by each participant. However, Fig. 4 shows the same trends as Fig. 3: laser scanners provided reasonable repeatability. Further, relative to the Type II device, they provided reasonably close floor levelness values but higher floor flatness values. For laser imaging devices, the minimum and maximum reported floor levelness and floor flatness values are 15 and 21 and 17 and 34, respectively.

Podium-level individual sample measurement lines—The F-numbers for each of the 12 sample measurement lines are plotted against measurements taken using a Type II device in Fig. 5 and 6. Figure 5 shows the floor flatness comparison and Fig. 6 the floor levelness comparison. The figures show significant differences, with Fig. 5 showing a systematic error of the laser floor flatness measurement, and Fig. 6 showing a random error for the laser floor levelness. The cause of the systematic error for floor flatness is unclear.

Table 4:
Ground-level composite F-numbers obtained using laser measurements

Participant	Ground	F_F	F_L	Lines
A	Day 1	29.79	19.83	Parallel/Perpendicular
	Day 2	30.04	19.83	Diagonal
	Difference	0.25	0.00	—
B	Day 1	31.30	16.60	Parallel/Perpendicular
	Day 2	32.00	16.60	Diagonal
	Difference	0.70	0.00	—
C	Day 1	29.64	20.57	Diagonal
	Day 2	28.37	20.91	Parallel/Perpendicular
	Difference	1.27	0.34	—
D	Day 1	32.56	23.97	Diagonal
	Day 2	34.41	20.55	Parallel/Perpendicular
	Difference	1.85	3.42	—
E	Day 1	31.13	19.51	Parallel/Perpendicular
	Day 2	30.04	17.86	Diagonal
	Difference	1.09	1.65	—
F	Day 1	17.47	14.88	Parallel/Perpendicular
	Day 2	17.77	14.94	Parallel/Perpendicular (same lines)
	Difference	0.30	0.06	—
G	Day 1	24.90	17.90	Diagonal
	Day 2	24.30	18.00	Diagonal (same lines)
	Difference	0.60	0.10	—
H	Day 1	21.90	16.30	Diagonal
	Day 2	26.60	19.60	Parallel/Perpendicular
	Difference	4.70	3.30	—

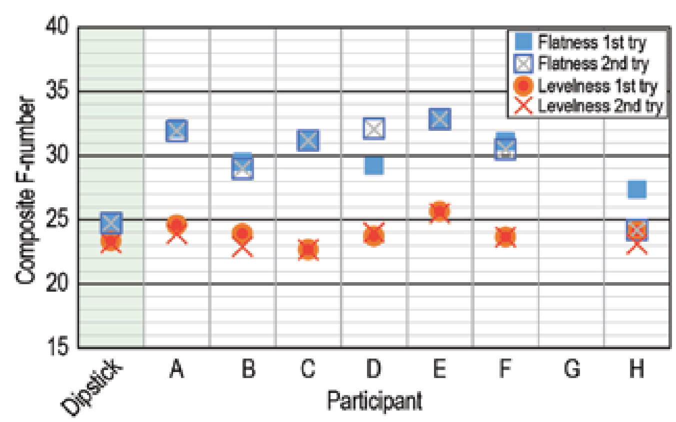

Fig. 3: Composite F-numbers determined on the podium level. F-numbers measured by laser imaging devices are shown to be reasonably repeatable. The composite floor levelness measured by the laser imaging devices were in reasonable agreement with those measured by a Type II device. The composite floor flatness measured by the laser imaging devices was consistently higher than that measured by a Type II device

Laser scan repeatability and reproducibility—Table 5 provides the repeatability standard deviations for within-laboratory and multiple-laboratory testing on the podium level, where the same 12 sample measurement lines were measured twice with a laser scanner. The table also shows the ASTM E1155 repeatability standard deviations for a Type II device. The within-laboratory repeatability standard deviation for F_L for the laser scanner measurements from seven participants is slightly higher compared to the Type II device, but it is slightly lower for the laser scanner measurements

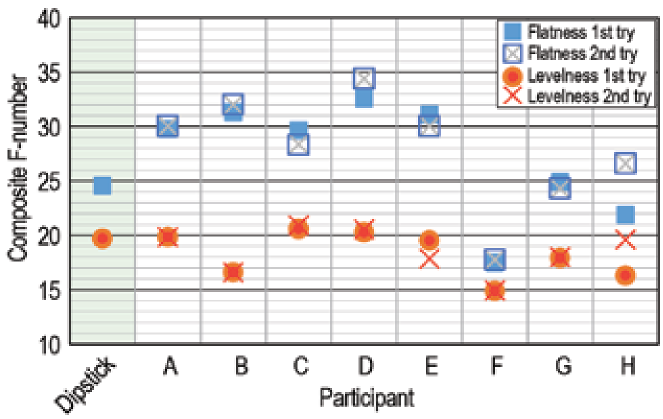

Fig. 4: Composite F-numbers determined on the ground level. F-numbers measured by laser imaging devices are shown to be reasonably repeatable. Five of the eight composite floor levelness values based on laser imaging data were in reasonable agreement with the floor levelness obtained using a Type II device. However, most of the composite floor flatness values based on laser imaging data were significantly higher than the floor flatness obtained using a Type II device

from five participants using the same software. The data also show that the within-laboratory and multiple-laboratory repeatability standard deviations for F_F for the laser scanner are much higher compared to the Type II device.

Table 6 provides the reproducibility standard deviations for within-laboratory and multiple-laboratory testing on the ground level where different sample measurement lines were measured twice with a laser scanner. The data show that the multi-laboratory reproducibility standard deviations for F_F for the laser scanner are much higher compared to the Type II device except for the value obtained for five participants using the same software. The data also show that the multi-laboratory reproducibility standard deviations for F_L for the laser scanner are slightly higher or lower compared to the Type II device.

What is the practical significance of repeatability and reproducibility? If the same laboratory or multiple laboratories measure an F_F 30 and F_L 20 floor, it is anticipated that 95% of the repeat measurements will be as follows.

For a Type II device:

- Repeatability, same laboratory, same lines—0.71 for F_F and F_L;
- Repeatability, multiple laboratories, same lines—0.85 for F_F and F_L; and
- Reproducibility, multiple laboratories, different lines—3.45 for F_F and 4.95 for F_L.

For a laser imaging device:

- Repeatability, same laboratory, same lines—2.63 for F_F and 1.13 for F_L;
- Repeatability, multiple laboratories, same lines—6.79 for F_F and 2.77 for F_L; and

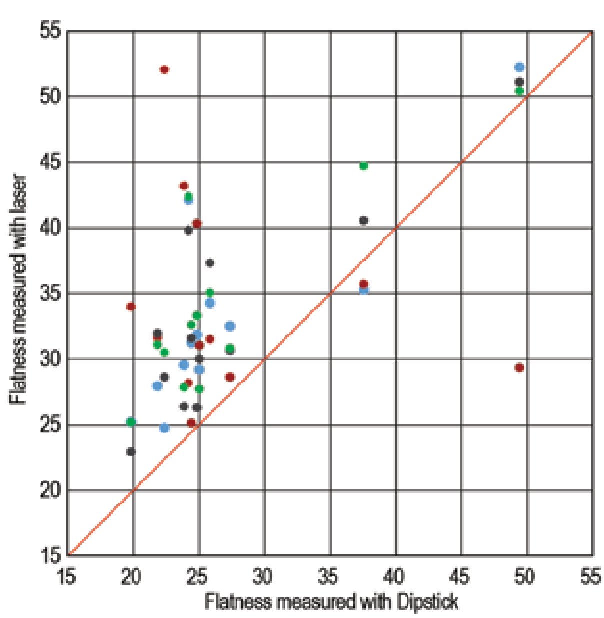

Fig. 5: A comparison of laser and Type II device floor flatness numbers for the 12 sample measurement lines on the podium level. There appears to be a systematic error involved with the floor flatness values as they are consistently above the line of equality

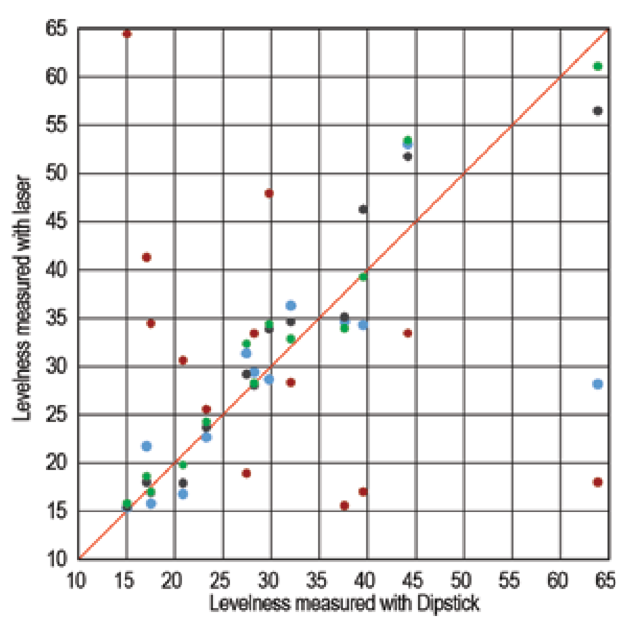

Fig. 6: A comparison of laser and Type II device floor levelness numbers for the 12 sample measurement lines on the podium level. There appears to be a random error involved with the floor levelness values as they are scattered above and below the line of equality

- Reproducibility, multiple laboratories, different lines—9.31 for F_F and 5.38 for F_L.

Additional Study and Recommendations

The ASCC study did not successfully obtain a reasonable comparison of floor flatness values obtained by the Type II device and those obtained with laser imaging devices.

Although ASTM E1155 permits the use of a laser imaging device to collect F-numbers, Note 3 cautions users that "all project participants" should agree on the exact test apparatus to be used "prior to the application" for contract specification enforcement:

"NOTE 3: Since the bias of the results obtained with this test method will vary directly with the accuracy of the particular measurement device employed, all project participants should agree on the exact test apparatus to be used prior to the application of this test method for contract specification enforcement."

In addition to the study conducted in Walnut Creek, ASCC is collecting additional F-number measurement correlations between the Type II device and laser imaging devices. Table 7 shows results collected on a more recent project. Two operators used different devices (Dipstick and a laser) and different sample measurement lines to determine reproducibility.

Given that z_i readings obtained using the two types of instruments were determined on different sample measurement lines, we believe that F-number differences of up to 3 would be reasonable. Referring to Table 7, differences falling within this range are highlighted in green and differences falling outside this range are highlighted in red.

We have not been able to determine the conditions that would allow the two types of instruments to consistently provide reasonable agreement. Until such time that we are confident in consistently obtaining reasonable comparisons, we are unable to recommend the use of a laser imaging device for F-number specification compliance.

Table 5:
Podium-level composite F-numbers for 12 sample measurement lines, repeated twice

Device type	Repeatability standard deviation			
	Within-laboratory testing		Multiple-laboratory testing	
	F_F	F_L	F_F	F_L
Type II device (ASTM E1155)	0.25	0.25	0.30	0.30
Laser imaging device*	0.93	0.40	2.40	0.98
Laser imaging device†	0.65	0.20	0.76	1.16

*Seven participants; one participant could only measure diagonal lines

†Five participants using two different manufacturers lasers but with the same software program

Table 6:
Ground-level composite F-numbers for participant-selected sample measurement lines, repeated twice

Device type	Reproducibility standard deviation			
	Within-laboratory testing		Multiple-laboratory testing	
	F_F	F_L	F_F	F_L
Type II device (ASTM E1155) at F_F 29 / F_L 19	NA	NA	0.74	0.70
Type II device (ASTM E1155) at F_F 30 / F_L 21	NA	NA	1.22	1.75
Laser imaging device* at F_F 30 / F_L 19	1.46	1.29	3.29	1.90
Laser imaging device† at F_F 28 / F_L 19	1.19	0.98	5.23	2.38
Laser imaging device‡ at F_F 31 / F_L 20	0.90	1.55	1.69	1.33

*Six participants as two participants used the same layout patterns on both days

†All eight participants regardless of layout pattern

‡Five participants using two different manufacturers lasers but with the same software program

Table 7:
Reproducibility of F-numbers with Dipstick and laser measurements

Building	Pour	F_F			F_L		
		Dipstick	Laser	Difference	Dipstick	Laser	Difference
A	1	48.10	55.90	7.80	32.62	26.20	6.42
A	2	46.73	52.64	5.91	29.17	32.13	2.96
B	1	38.79	40.74	1.95	35.53	33.46	2.07
B	2	34.39	33.85	0.54	30.56	27.67	2.89

Project credits

Tony Joyce, Avalon Bay Communities, Owner/General Contractor; Tom Sprague, Don Thornburg, and Marty Conroy, Conco, Concrete Contractor; Jose Jacobo, Hector Campos-Diaz, and Anil Nethisinghe, Consolidated Engineering Laboratories (CEL), Testing Agency; and Eric Peterson, Webcor Construction LP, Observation.

Laser scanning participants

- Andy Huntley, TAS Commercial Concrete;
- Aniruddha Anjana, Baker Concrete Construction;
- Cutter Shea, Faro Technologies, Inc.;
- Leo Castillo and Leeroy Duarte, VEC, INC.;
- Nathan Culver and Gustav Choto, Trimble Inc.;
- Kevin Stein, Steve Smith, and Heather White, BKF Engineers;
- Josh Engelbrecht, DPR Construction;
- Brandon Kovarick, CECO Concrete Construction; and
- Leo Zhang, Conco.

References

1. Paul, W.; Klinger, J.; and Suprenant, B.A., "ASCC 3-D Laser Scanning Study," *Concrete International*, V. 41, No. 1, Jan 2019, pp. 22-29.

2. "Dipstick®: The Most Accurate Concrete Profiler," Face® Construction Technologies, Norfolk, VA. Accessed Jan. 6, 2020. https://facecompanies.com/dipstick/.

Note: Additional information on the ASTM International standard discussed in this article can be found at **www.astm.org**.

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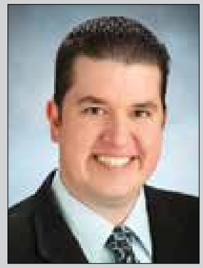

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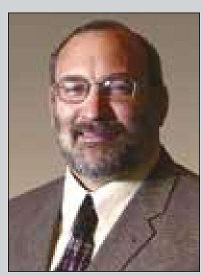

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